

A COMPARISON OF THE WIND SPECTRA CALCULATED FROM DATA OBTAINED BY INDEPENDENT SAMPLING METHODS¹

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ABSTRACT

The power spectrum of the wind is estimated from independent wind measurements taken at an altitude of 1,500 ft above the ground in the frequency band from 0.0625 to 1.5 cycles hr^{-1} . Wind data were obtained simultaneously from radar tracking equipment and from wind sensors on a nearby tower. These data were collected at 20-min intervals over a 5-day period.

Analyses of the wind spectra and coherence indicated a good correspondence in the two time series, considering that the data were obtained at slightly different locations and by completely independent measurements. It is concluded that radar wind-finding measurements can provide valid estimates of the wind spectrum in the frequency band analyzed.

1. INTRODUCTION

The power spectra of the wind in the upper troposphere have been obtained in previous studies (Mantis 1963, Chiu 1960) using RAWIN data; however, investigations of the wind spectrum near the earth's surface usually are based on data collected by sensors located on instrumented towers (Van der Hoven 1957, Gifford 1955). Consequently, estimates of the wind spectrum are based upon two independent methods of observation. Comparisons of the wind spectra calculated from data obtained by these independent methods have not been made because: 1) the time interval between observations of the upper level winds is generally several hours or more in duration, while the time interval between tower sensor readings is on the order of a few seconds or minutes with a period of observation of a few hours or less, resulting in spectral estimates for frequency bands that do not overlap; 2) the upper wind measurements generally are obtained above the planetary boundary layer, whereas the tower wind measurements are in the lower levels of the boundary layer; and 3) simultaneous observations are rarely available at the same location by both observational methods.

A comparison of the wind spectra obtained by these two observational methods requires wind data measurements from sensors located on towers at a level far above the surface and simultaneous RAWIN measurements of the upper winds for a thin layer centered at the sensor level. These requirements, plus the difficulty in releasing balloons for wind-finding purposes more frequently than every 20 min over periods of several days, limit the spectral band for the comparison to frequencies in the range of about 0.05 to 2 cycles hr^{-1} . This frequency band lies

within the low-frequency portion of the wind-speed spectral "gap" as determined by Van der Hoven (1957).

2. SOURCE AND ACQUISITION OF THE DATA

The wind data used in this study were obtained from a special series of radar-tracked balloon (RABAL) observations in southern Nevada and from wind sensors on the 1,500-ft Bren Tower facility.

At the time of this study, the Bren Tower was located in Yucca Flat, a high mountain valley that is part of the Atomic Energy Commission's Nevada Test Site, located about 57 mi north-northwest of Las Vegas, Nev. A topographical map of the valley area is shown in figure 1. The basin of this valley is a dry lake bed generally outlined by the 4,000-ft contour. Notice that the RABAL observation site is about 10 mi from Bren Tower.

Between the two observation sites, the terrain slopes gently upward to the north; and, during good visibility, the base of the tower could be seen from the RABAL site. To the west and north of Yucca Flat are some rather extensive mesas which have a ridge line about 1,500 ft above the valley basin.

The system used for tracking the weather balloons was a modified M-33 antiaircraft track radar. The system has a plotting board which provides plots of the balloon position, at intervals of 15 sec or longer.

As far as tracking accuracy is concerned, Booth (1966) noted that the unmodified system is within 1 or 2 ft of target position for ranges up to 1 mi; however, the modified track system may not be this accurate. The accuracy of the wind observations obtained with this system depends upon radar-positioning accuracy, plotting accuracy, and observer accuracy in reducing the data from the plot board. It is believed that, all things being

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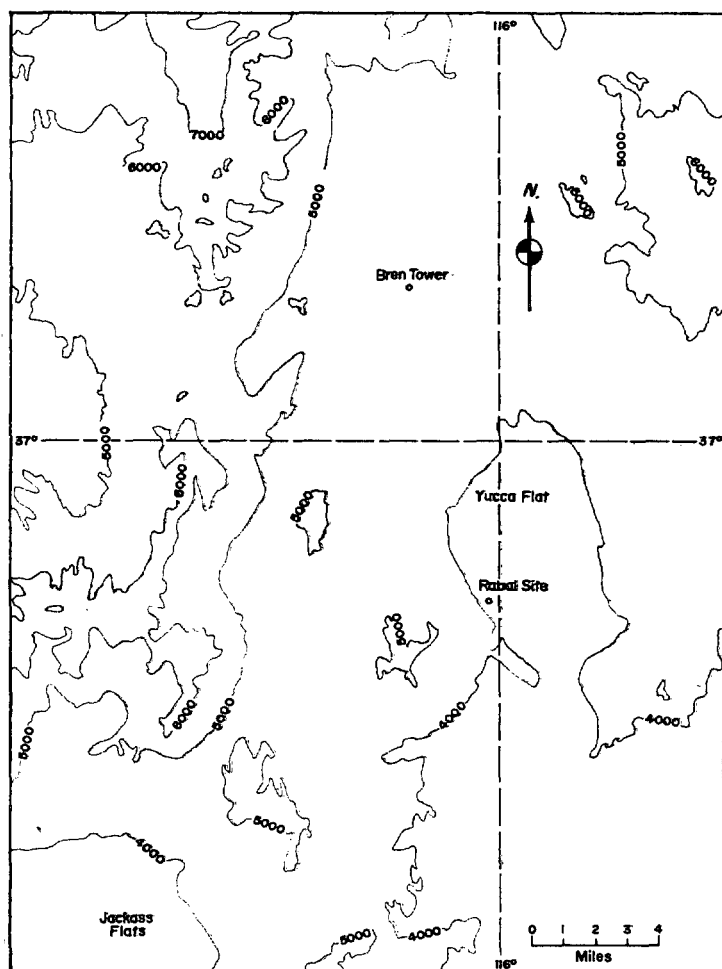


FIGURE 1.—Topography of Yucca Flat, Nev., with the locations of the observing sites.

considered, the wind directions obtained from the radar equipment probably are accurate to within 3° , while the wind speed error is about ± 2 kt if the winds are computed from 1-min differencing of the position data.

The RABAL data were obtained by the following procedures:

- 1) A standard U.S. Weather Bureau balloon (100 gm) with a radar target attached was released from the RABAL site every 20 ± 2 min from 0700 PST (120th meridian civil time) on January 27 until 0700 PST on Feb. 1, 1964, a period of 5 days. This resulted in a total of 360 wind observations.

- 2) The radar plots of the balloon xyz position were used to determine wind directions and speeds for a 500-ft layer centered at 1,500 ft above the surface. Thus a difference over a specified vertical displacement was used rather than the usual specified time interval. In general, it took about 1.5 min for the balloon to travel from its surface release point to 1,750 ft. Only about 30 sec were required to traverse the 500-ft layer.

The wind instrumentation on the Bren Tower consisted of Beckman and Whitley 1733 sensors² mounted at the

² Mention of commercial products does not constitute an endorsement.

TABLE 1.—Statistics of the data (Jan. 27–Feb. 1, 1964)

Data	Direction (deg)		Speed (kt)		u -component (kt)		v -component (kt)	
	Mean	Var	Mean	Var	Mean	Var	Mean	Var
Bren	010	6337	7.0	22.6	-2.2	17.4	-3.7	37.4
RABAL	351	4634	6.5	19.7	-0.6	10.8	-3.9	35.9

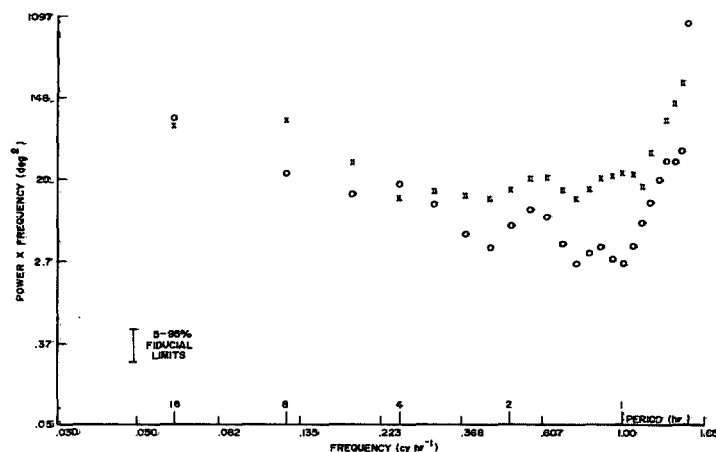


FIGURE 2.—Spectral estimates of the wind direction for the Bren Tower (x) and the radar-tracked balloon data (o).

1,500-ft level and coupled to separate direction and speed analog recorders. Typical recording errors for this type of observation system are, according to the manufacturer's specifications, $\pm 3^\circ$ for direction and ± 3 percent for speed. The timing mechanism for the wind recorders is electrically driven.

The wind recorder charts were read with a strip chart reader coupled to a keypunch machine. A series of tests showed that the chart reader could determine direction to within 4° and speeds to about ± 1 mi hr^{-1} of the actual chart values. The raw data were subjected to 2-min averaging at 20-min intervals corresponding to the balloon release times.

3. DISCUSSION OF RESULTS

The means and variances of the wind data obtained during the observation period are presented in table 1. In general, the winds were northerly and relatively slow in speed at both observation sites. Consequently, balloons released from the RABAL site drifted, in the mean, less than 0.2 mi southward from the release point while passing the 1,500-ft level. As compared with Bren Tower data, the RABAL data had less variance in both speed and direction, particularly in the u -component of the wind.

The results of the analyses of spectra are presented in figures 2 through 5. In these figures, for the power spectra the abscissas are labeled as frequency and period on a logarithmic scale labeled in units of (cycles hr^{-1}) and (hr), respectively. The plotted points are the product of frequency

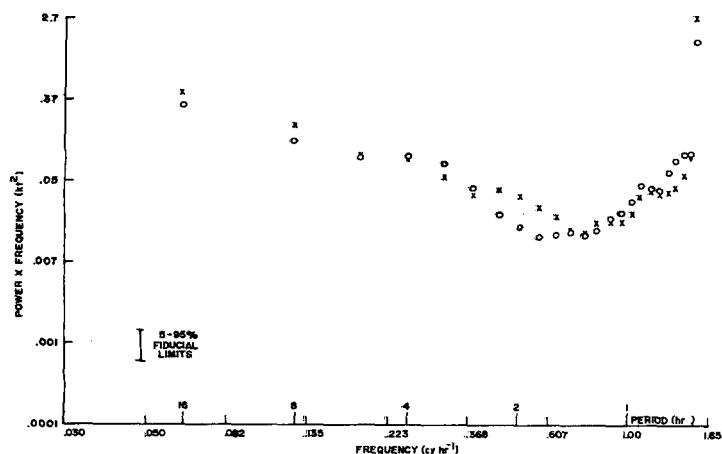


FIGURE 3.—Spectral estimates of the wind speed for the Bren Tower (x) and the radar-tracked balloon data (o).

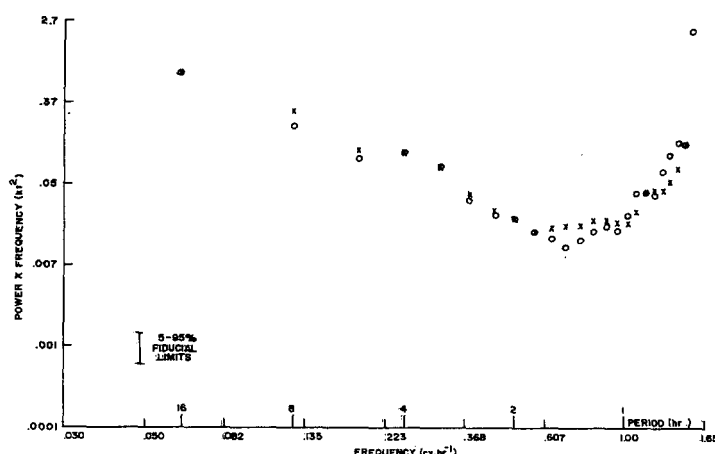


FIGURE 5.—Spectral estimates of the v -component wind for Bren Tower (x) and the radar-tracked balloon data (o).

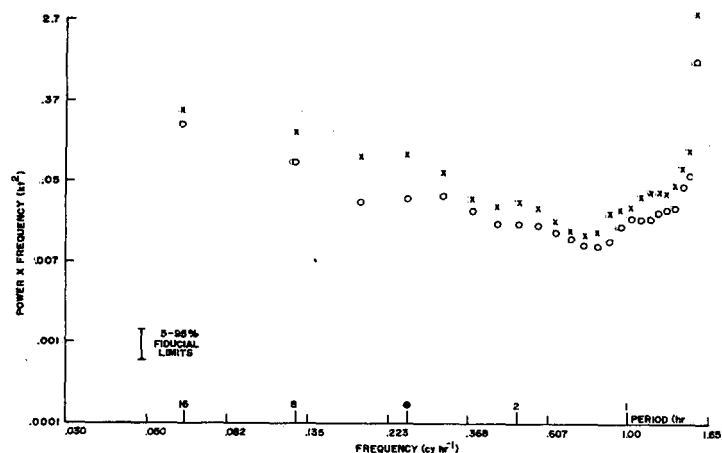


FIGURE 4.—Spectral estimates of the u -component wind for Bren Tower (x) and the radar-tracked balloon data (o).

and spectral power which allows the area under a curve through the points to represent variance.

The method of spectral analysis is based on the Fourier transform of the autocorrelation function (Blackman and Tukey 1959) of equal-spaced discrete data. A maximum of 24 lags was used to obtain spectral estimates in the frequency band from 0.0625 to 1.5 cycles hr^{-1} , giving about 30° of freedom for each spectral estimate. The confidence limits for the 5 to 95 percent probability levels are shown as vertical bars in the spectral diagrams. Coherences also were calculated for this frequency band. The lower limit of significance at the 5 percent probability level is indicated as a dashed horizontal line on the coherence diagrams.

The spectral analyses in figures 2 through 5 show a relatively large variance at the low-frequency end of the band. In the high-frequency portion of the spectrum, considerable aliasing is evident as indicated by the extremely rapid rise in variance for the last 20 or 30

percent of the spectral estimates. This effect indicates that a considerable amount of variance is present in these wind data for frequencies above 1.5 cycles hr^{-1} . The general form of the spectra is remarkably similar when one considers that the data were measured at different locations by completely different observation methods, and that the Bren Tower data were time smoothed while the RABAL data were both time and space smoothed.

Notice that the direction spectra (fig. 2) are less similar than are the spectra of the speed and components (figs. 3-5). The RABAL direction spectrum has considerably less power in the high-frequency portion of the band than does that of the Bren. This difference could be the result of a reduced aliasing effect in the RABAL direction data, because the RABAL data probably were subjected to more smoothing than the Bren data, but this does not appear to be the case for the speed and component spectra in figures 3 through 5.

The area under a curve through the spectral estimates in figures 2 through 5 is directly proportional to the variance. In each case, the area under the RABAL spectral curves is less than that under the Bren spectral curves. This result agrees with the variances given in table 1. Hence, the variances from the spectral analyses are consistent with the total variance of the time series which, therefore, provides a rough check on the accuracy of the spectral analyses. Furthermore, it appears that the more closely the variances agree in table 1, the more similar are the corresponding spectral estimates. For example, notice that there is a smaller difference between variances of the v -component than those of the u -component; correspondingly, the spectral estimates of the v -component for the Bren and RABAL wind are more similar than the spectral estimates of the u -component.

Coherence is a measure of the relationship between two time series, "it can vary from 0 to 1," and it is analogous to the square of the correlation coefficient, except that the coherence is a function of frequency. In general,

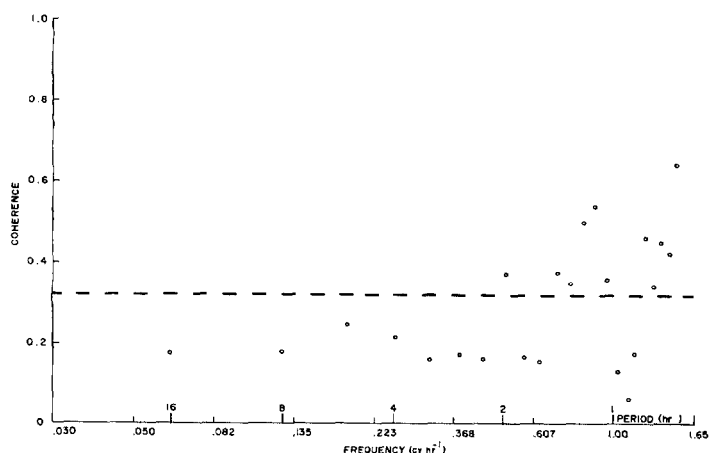


FIGURE 6.—Wind-direction coherence between the Bren Tower and the radar-tracked balloon data.

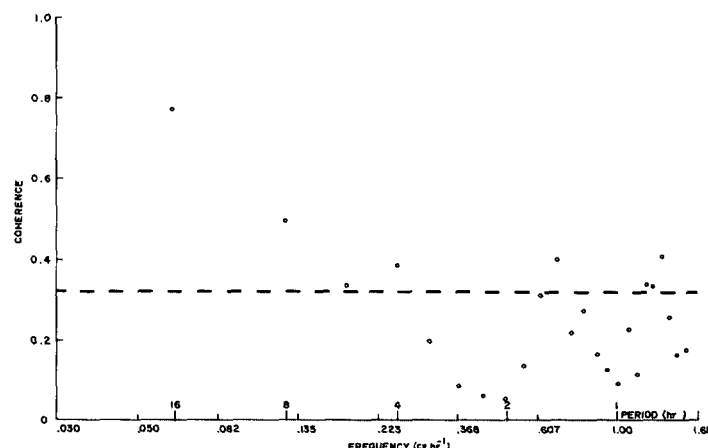


FIGURE 8.—The v -component wind coherence between the Bren Tower and radar-tracked balloon data.

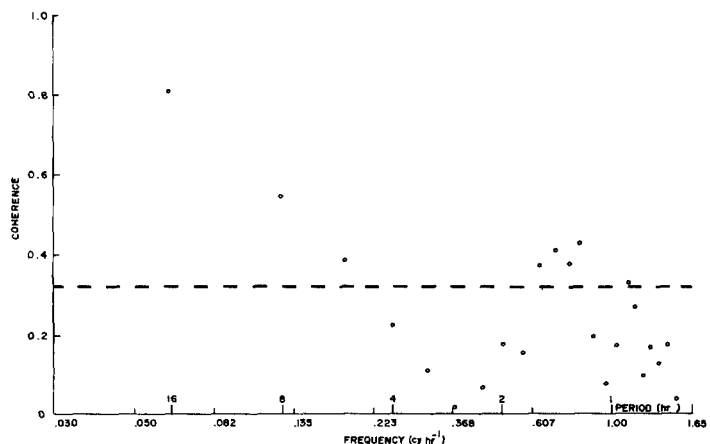


FIGURE 7.—Wind-speed coherence between the Bren Tower and radar-tracked balloon data.

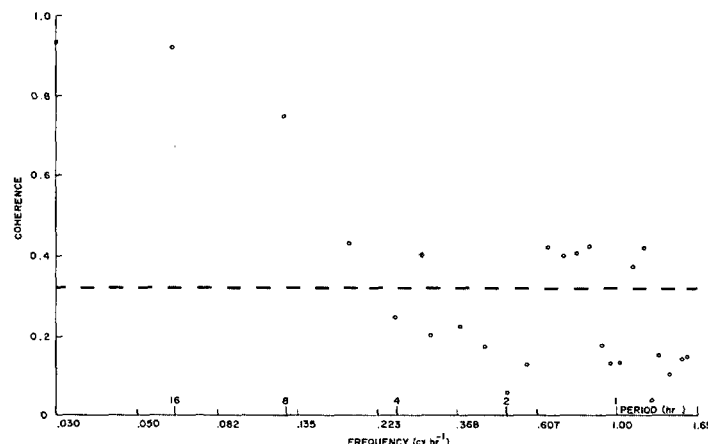


FIGURE 9.—The u -component wind coherence between the Bren Tower and radar-tracked balloon data.

figures 6 through 9 show that the coherences for speed and the u - and v -components are relatively high at low frequencies and rapidly decrease to small or insignificant values at higher frequencies. However, the direction coherence is small or insignificant for all frequencies. The relatively high coherence (that is, high correlation) for the speed and u - and v -components at the low-frequency end of the band probably reflects the synoptic scale and diurnal wind systems which affect both observation sites at the same time. However, there are other statistically significant peaks in each of these diagrams, one centered near 0.7 cycle hr^{-1} and the other roughly 1.2 cycles hr^{-1} . The latter peak in coherence may be spurious because it is based on spectral estimates which were affected by a high degree of aliasing. This does not appear to be the cause of the peak near 0.7 cycle hr^{-1} , since four coherence estimates (at least for the speed and v -component) that lie above the line of statistical significance are involved and the peak is located in a part of the frequency band

where the aliasing effect on the spectral estimates is considerably reduced. The apparent correlation in the data at this frequency (0.7 cycle hr^{-1}) may be the result of eddies which, as they move downstream with the mean wind flow, pass both observation sites. Evidence of this possibility is indicated by the fact that the two observation sites happen to lie on a line nearly parallel to the mean wind direction, which allows a computation of the lag time at which the maximum correlation in the wind between the two sites would occur. According to Lumley and Panofsky (1964), the maximum correlation for eddies moving between two anemometers would occur at a lag time given by

$$\Delta t = (\Delta X)V^{-1} \sec \alpha, \quad (1)$$

where ΔX is the separation distance, α is the angle between the wind direction and the anemometer line, and V is the mean wind speed. Substitution into equation (1)

yields a lag time of 1.53 hr, if an average of the mean wind at the Bren Tower and RABAL sites (see table 1) is used in the computation. This would correspond to a frequency of $(1.53)^{-1} = 0.68$ cycle hr^{-1} , which closely agrees with the frequency of the secondary coherence peak at 0.7 cycle hr^{-1} . Thus, the concurrent observations confirm what is predicted by equation (1).

Although the power spectra of the u - and v -components do not indicate any significant peaks, both the Bren and RABAL direction spectra (fig. 2) indicate a minor peak centered near 0.6 cycle hr^{-1} . A possible explanation of why the spectral peak appears with direction but not the speed or components is that at the slow wind speeds observed the speed variance would be small, whereas there is no such restriction placed on the direction.

If it may be assumed that the waves causing this spectral peak travel with the mean wind speed, then the wavelength can be computed from

$$L = cf^{-1} \quad (2)$$

where c is the wave speed and f is the frequency. Substitution into equation (2) gives a wavelength of about 21 km if an average of the mean speed at the Bren and RABAL sites is used in the calculation.

The wavelength and wave frequency are in approximate agreement with those found by Tyson (1968) in the down-valley mountain winds around Pietermaritzburg, South Africa. Tyson's study of the horizontal velocity spectra of the mountain wind near the ground shows that maximum turbulent energy is generated by waves the order of 10 km in length and frequency of 1 cycle hr^{-1} .

4. CONCLUSIONS

The similarity in spectral analyses of the Bren Tower and RABAL data indicates the upper wind observations at frequent intervals may be used to obtain valid wind spectrum estimates in the spectral "gap." Consequently, studies of the mesoscale portion of the wind spectrum might be less costly if wind data were obtained from a network of mobile radar tracking systems rather than wind sensors located on a network of towers.

The spectral analyses indicate that waves on the order of 20 km in length with an oscillation frequency near 0.6 cycle hr^{-1} were occurring in the down-valley wind in Yucca Flat.

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